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# **National Plant Breeding Study-I**

Human and Financial Resources  
Devoted to Plant Breeding  
Research and Development  
In the United States in 1994

**IOWA STATE UNIVERSITY**

Iowa Agriculture and Home Economics  
Experiment Station

Cooperative State Research,  
Education & Extension Service / USDA cooperating

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## SUMMARY

A survey was conducted to determine the number of science person years (SY) that were devoted to plant breeding research and development (R&D) in the United States public and private sectors. Also, via estimates of cost per SY, annual dollar expenditures for plant breeding were estimated. Data were collected on plant breeding R&D activities defined as (a) basic plant breeding research (PBR), (b) genetic enhancement (GE), and (c) cultivar development (CD), and on SY input per crop and crop group.

The primary findings were:

1. The total number of SYs devoted to plant breeding R&D in the United States is 2,241. The distribution of SYs is 1,499 in private companies, 529 in state and territorial agricultural experiment stations (SAES), 177 in the Agricultural Research Service of the U.S. Department of Agriculture (ARS/USDA), and 36 in the Plant Materials Centers/USDA (PMC/USDA).
  2. Over the 5-year period 1990-94, the net loss of plant breeding SYs in SAES was estimated to be 12.5 or 2.5 SYs per year. For the same period, private industry was estimated to have a net growth of 160 SYs or 32 SYs per year. Over public and private sectors, 372 SYs were devoted to PBR, 403 SYs to GE, and 1,430 SYs to CD. Proportions of SYs devoted to these 3 R&D activities vary by employment category. In SAES, percentages of SYs devoted to PBR, GE, and CD were 30, 29, and 41, respectively; in ARS/USDA they were 40, 48, and 12, respectively; and in private industry they were 9, 11, and 80, respectively.
  4. Crop groups with more than 100 SYs were cereal grains with 892, fruit vegetables with 213, grain legumes with 207, fiber crops with 136, forages with 122, temperate fruit and nut crops with 105, and oilseed crops with 104.
  5. More than 25 SYs are devoted to each of 16 U.S. crops. Field corn led with 545 SYs or 25% of all plant breeding SYs in the United States. Next were soybean with 156 SYs, cotton with 134 SYs, and wheat with 131 SYs. Crops with 50 to 100 plant breeding SYs are tomato, alfalfa, sorghum, and potato.
  6. Private industry emphasizes the breeding of crops that use hybrid cultivars in agricultural production. Of the 16 crops to which private industry devotes 20 or more plant breeding SYs, 6-corn, sorghum, sunflower, sweet corn, sugar beet, and muskmelon-with entirely hybrid cultivars account for 654 SYs. Three crops with both hybrid and pure line cultivars-tomato, pepper, and onion-account for 119 breeding SYs in private industry. Six crops with pure line cultivars-cotton, wheat, soybean, canola, rice, and lettuce-account for 328 SYs.
- In contrast, the public sector has 11 crops with 15 or more breeding SYs, and 7 are dominated by pure line cultivars.
7. Private industry is estimated to spend \$338 million on plant breeding R&D annually or 61% of the U.S. annual expenditure whereas the public sector is estimated to spend \$213 million or 39%.

## **INTRODUCTION**

The profession of plant breeding has changed greatly over the past quarter century. In the U.S. and many other countries, laws were written and refined that permitted the protection and/or patenting of biological materials, including plant cultivars. This practice of protection of genes, parent lines, and cultivars has led to a much more formalized protocol for interaction among plant breeders, from both the public and private employment sectors. Also, research in molecular biology has led to techniques, grouped under biotechnology, that greatly expand the array of genes available to plant breeding programs and that can make plant breeding much more precise. As a result of cultivar protection and the prospective use of biotechnology in plant breeding, there had been an immense increase in plant breeding by private companies. This evolution within the plant breeding arena raises questions about many issues.

We decided to undertake a National Plant Breeding Study to be divided into several phases. Phase I involved making a comprehensive compilation of the number of Science Person Years (SY) devoted to the U.S. plant breeding industry in total, by employer category (i.e., state agricultural experiment stations-SAES, U.S. Department of Agriculture-USDA, and private industry), by plant breeding activity (i.e., basic plant breeding research-PBR, germplasm enhancement-GE, and cultivar development-CD), and by crop and crop category.

Estimates of cost per plant breeding SY were obtained from stratified random samples of employers in the public and private sectors. Mean values were used to estimate the annual cost of U.S. plant breeding R&D and the input by employer category. Further, the net loss and gain of SYs were estimated for the public and private sectors over the past 5 years.

This report is a compilation of the data obtained from the survey.

## **METHODS AND MATERIALS**

A questionnaire was constructed with help from the Survey Unit of the Statistical Laboratory at Iowa State University (see Appendix D). The questionnaire requested data, with 1994 being the base year, on numbers of SYs devoted to PBR, GE, and CD by crop from each employer (see questionnaire for definitions of SY and plant breeding activities). Also requested was whether an employer's input had changed over the 5-year period 1990-94. These data were used to estimate net gains or losses in SYs by employer category.

Data on ARS/USDA input into plant breeding research and technology were obtained from Charles Murphy of the National Program Staff/ARS. The questionnaire also was sent to 28 USDA Plant Materials Centers (PMC) that select species and accessions of plants for land conservation purposes. Replies were obtained from 26 PMCs. The questionnaire was sent to 50 SAES, 2 universities not associated with the SAES, 6 experiment stations in territories administered by the U.S. government, and 17 1890s colleges. Replies were obtained from all SAES, the 2 universities, 5 of the territorial experiment stations, and 6 1890s colleges.

A number of address lists were used to compile a group of private companies to receive the questionnaire. The primary data bases were the membership lists of the American Seed Trade Association (ASTA) and the National Council of Commercial Plant Breeders (NCCPB), company names provided by the chairs of Commodity Germplasm Committees, and state seed trade associations. Several other small association address

lists were also used. The integrated list with more than 1,000 seed companies and names of individuals was categorized by state, and these state lists were sent to 1 to 3 plant breeders in each SAES with requests to purge companies that were known to not have plant breeding programs. After this iteration, the list contained 690 companies and individuals to whom the questionnaire was sent. About 300 replies were obtained from this mailing. Attempts were made to contact the non-responders by phone. The questionnaire was mailed on 20 June 1996 and by 1 November when the survey was terminated, replies had been obtained via mail or phone from 584 companies and individuals. Of the 106 with no replies, 69 could not be contacted by mail or phone (it is assumed that these companies and individuals are no longer in the seed business), 22 had been bought by other companies on the list (their SY data were included in buying companies' replies), 2 refused to provide data, and 13 provided no data in spite of verbal promises to do so. Of the 584 companies from which replies were obtained, 329 reported SY data and 255 reported having no in-house plant breeding R&D. The 15 companies that refused or did not participate in the survey equaled 2.5% of the 599 companies and individuals that are known to be in business. If this group of 15 have the same percentage with PBR as did the group of 584 (56%), data was not obtained from 8 companies and individuals with an estimated 36 SYs.

Thus, the data obtained represents 100% of plant breeding SYs from the SAES and USDA and an estimated 97.5% of the plant breeding SYs in private industry.

In addition to putting U.S. annual plant breeding expenditure in terms of SYs, we have estimated an annual dollar input also. Although, we have attempted to collect SY data from all institutions and companies that do plant breeding R&D, data on dollar costs per SY were obtained from samples of institutions and companies. SAES were requested to provide data on cost per plant breeding SY for several crops. A weighted mean was obtained from these data (Table 16). The cost per plant breeding SY in ARS/USDA was provided by a member of the National Program Staff/USDA (Table 16). Companies were stratified according to number of SYs and 175 were asked to provide data on cost per plant breeding SY. One hundred replied, with 2 declining to provide data. Estimates from the remaining 98 were placed in the proper strata and mean values were computed for the 6 strata given in Table 15.

## **PAST STUDIES**

Several studies have been completed over the past 15 years to assess (a) numbers of SYs or Full Time Equivalents (FTEs) devoted to plant breeding in the United States and (b) changes that are occurring in planting breeding SYs or FTEs over time. None of these is exactly comparable to our survey, but each does provide some data that are useful for comparison purposes.

Brooks and Vest (1985) surveyed for breeding of horticultural crops in the public sector (i.e., SAES and USDA). They received replies from all 98 institutions surveyed and the ARS/USDA, and from these data they predicted a 13% decrease in FTEs devoted to plant breeding of horticultural crops in the public sector from 1983 to 1990, i.e., from 179 to 156 FTEs. Collins and Phillips (1991), while conducting a survey of land-grant universities and 1890s colleges on graduate training in plant breeding, found that the numbers of plant breeding FTEs in these institutions for all crops were 477 and 459 in 1980 and 1989, respectively. This equated to an FTE loss of 1.8 per year during the 1980s.

James (1990) surveyed the SAES and ARS/USDA with 100% return and reported that in 1989 the public sector supported 417 plant breeding FTEs, with 283 in the SAES and

134 in ARS. This study reported 144 FTEs in horticultural crop breeding, which was 19.6% less than the 179 FTEs that Brooks and Vest (1985) reported for 1983 and 8% less than the 156 FTEs these authors predicted for 1989. A survey by Collins and Phillips (1991) showed that the SAES supported 354 FTEs in breeding of forage and field crops in 1984-85. This study projected 385 plant breeding FTEs in SAES in 1990.

Kalton and Richardson (1983) sent a survey to 175 private companies with plant breeding programs and received replies from 160. Their data were not reported in FTEs, but rather as numbers of BS, MS, and PhD scientists involved in plant breeding. They found that the 160 companies employed 1,191 scientists with 41%, 23%, and 36% holding BS, MS, and PhD degrees, respectively. About 23% (276) of these scientists were breeding horticultural crops. Kalton et al. (1989) conducted another survey of 203 companies of which 157 replied. The number of plant breeding FTEs reported was 1,568, with 37%, 20%, and 43% holding BS, MS, and PhD degrees, respectively.

All these studies and our study were aimed at estimating the numbers of plant breeding FTEs or SYs in the United States. No one of them subjected the public and private sectors to the same survey or questions. Generally though, all agreed on a modest shrinking of plant breeding in the public sector and a sizable increase in plant breeding in the private sector.

## **RESULTS**

The number of SYs devoted to plant breeding research and technology (R&D) in the United States in 1994 was 2,241 (Tables 1 and 2), with 529 (23%) in SAES, 177 (8%) in ARS/USDA, 1,499 (67%) in private industry plant breeding, and 36 (2%) in the PMC. The total number of SYs in SAES, ARS/USDA, and private industry is 2,205. (Because 98% of the plant breeding SYs are employed by SAES, ARS/USDA, and private industry, subsequent discussion will concentrate on the 2,205 SYs employed by these 3 employment categories.)

### **Trends in Plant Breeding Employment**

As stated earlier, none of the previous studies on plant breeding employment has been exactly comparable to the current National Plant Breeding Study (NPBS). However, comparisons can be made that relate to trends in employment of plant breeders. Brooks and Vest (1985) surveyed the public sector (SAES and ARS/USDA) in horticultural breeding. They found that, in 1983, 179 FTEs were employed in the public sector for breeding horticultural crops, and from the replies, they estimated that 13% of these FTEs and 22% of the horticultural breeding projects would be lost by 1990: Thus, in 1990 there would be 156 FTEs breeding horticultural crops in the public sector. In our study, however, we found 252 SYs breeding horticultural crops in the public sector. Brooks and Vest (1985) found 132 FTEs in SAES and 47 in ARS/USDA in 1983; Comparable values in 1994 were 187 SYs in SAES and 65 in ARS/USDA. No explanation is evident for either (a) the predicted downward trend not occurring or (b) our 1994 SY number being 73 higher than the 1983 FTE number. Both studies had complete returns from all SAES and ARS/USDA and the same crops were used in computing horticultural crop FTEs and SYs in breeding. James (1990), with 100% returns from the public sector, showed 144 FTEs in horticultural crop breeding in 1989; that is, 8% fewer FTEs than the 156 FTEs Brooks and Vest predicted for 1990. Thus, James (1990) did support a downward trend of horticultural crop breeding in the public sector. Kalton and Richardson (1983) estimated that 276 scientists were breeding horticultural crops in the private sector.

James (1990) found 417 plant breeding FTEs in the public sector in 1989, with 283 in SAES and 134 in ARS/USDA. Collins and Phillips (1991) reported that SAES employed 477 and 459 FTE plant breeders in 1980 and 1989, respectively. These 1980 and 1990 FTE values were 13% to 21 % lower than the number of plant breeding SYs we found.

Collins and Phillips (1991) showed that SAES supported 354 FTEs breeding field and forage crops in 1984-85, and our study showed 343 breeding SYs for these crops in the SAES in 1994. These 2 values are similar.

Our survey asked each respondent to estimate whether his/her institution/company has increased, decreased, or stayed the same in input into plant breeding R&D during the period 1990-94, and if change occurred, what was the percentage change. These replies, when applied to SYs, indicated that SAES had a net loss of 2.5 plant breeding SYs per year in the 1990s. This is a loss of only 0.5% per year.

Kalton and his colleagues concentrated their surveys on the major companies in the seed industry. Kalton and Richardson (1983), with a 90% survey return, found that private industry employed 1,191 scientists in plant breeding in 1981, and Kalton et al. (1989), with a 77% survey return, found 1,568 scientists doing plant breeding in the private sector in 1988. Our estimate from a 97.5% questionnaire return showed 1,499 plant breeding SYs in the private sector. Of the 329 companies that reported plant breeding SYs in our survey, 137 (42%) reported growth during 1990-94 and 20 (6%) reported decreases in inputs into plant breeding. When these data were translated into SYs, there was a net increase of 32 plant breeding SYs per year in the private sector during the 1990s. This is a gain of 2.4% per year.

Table 1. Numbers of SYs devoted to plant breeding arranged by employer and crop categories.

Crop category	Number of SYs employed by			Total
	SAES	ARS/ USDA	Private industry	
Cereal	155	34	703	892
Fiber	20	13	103	136
Forage	38	33	51	122
Fruit vegetable	38	8	167	213
Grain legume	67	14	126	207
Lawn & turf	15	--	41	56
Leafy, bulbous, & stem vegetables	16	2	77	95
Medicinal, spice, & special crops	6	4	5	15
Mushroom	1	--	2	3
Oilseed	24	6	74	104
Ornamental	18	5	64	87
Root & tuber	45	12	24	81
Stimulant	13	2	5	20
Sugar	4	15	25	44
Temperate fruit & nut	50	23	32	105
Tropical fruit & nut	10	6	--	16
Miscellaneous	9	--	--	9
Totals	529	177	1,499	2,205

Table 2. Numbers of plant breeding SYs employed in the Plant Materials Centers/USDA.

Crop group	Number of species	Number of Sys
Grasses	54	24.5
Legumes	21	3.2
Shrubs	20	3.6
Trees	25	3.1
Miscellaneous	19	1.8
Totals	139	36.2

Table 3. Numbers and percentages, in parentheses, of plant breeding SYs devoted to horticultural and agronomic crops arranged by employer.

Category	SAES	ARS/USDA	Private industry	Total
Horticultural	186 (35%)	65 (37%)	383 (25%)	634 (29%)
Agronomic	343 (65%)	112 (63%)	1,116 (75%)	1,571 (71%)
Totals	529	177	1,499	2,205

### Categories of Plant Breeding Employment

Of the 2,241 SYs in U.S. plant breeding, 1,499 (67%) are employed by the private industry sector, 529 (24%) are employed by SAES, and 213 (9%) are employed by USDA (Tables 1 and 2). Overall, 1,571 SYs are breeding agronomic crops, 634 are breeding horticultural crops, and 36 are breeding conservation crops (Tables 2 and 3). The proportions of SYs breeding horticultural vs. agronomic crops varies by employer. In the public sector, 35-37% of SYs are breeding horticultural crops whereas in the private sector this proportion is only 25%. James (1990) also found that 35% of public sector FTEs were breeding horticultural crops, and Kalton and Richardson (1983) estimated that 23% of private sector breeders worked on horticultural crops. Thus, the proportions of FTEs, SYs, or scientists devoted to horticultural and agronomic crops has remained fairly constant over the past dozen years in both the private and public sectors.

### Employment by Plant Breeding Activity

Survey respondents were asked to allocate SYs by 3 categories of research activity: (a) PBR, (b) GE, and (c) CD (see survey copy in Appendix D for definitions of these categories). As would be expected, the private sector has a much greater emphasis on CD than do either SAES and ARS/USDA. Eighty percent of the plant breeding SYs in the private sector was devoted to CD (Table 4). About 20 years ago, ARS/USDA made a commitment to devolve its CD: It appears that this agency has kept to this commitment because currently only 12% of its plant breeding SYs is devoted to CD. The SAES retain 41 % of their plant breeding SYs in CD.

Germplasm enhancement is of great importance to future CD because it generates the gene pools that will be used to produce superior cultivars a decade or 2 hence. It is somewhat surprising to find that more than 400 SYs, or about 19% of the total plant breeding SYs, are devoted to this activity. Even 11 % of SYs in private industry is devoted to GE. Germplasm enhancement is sometimes called "pre-breeding" and it can encompass (a) gene transfer from germplasm accessions, (b) increasing frequencies of desirable genes in crop gene pools, or (c) both a and b simultaneously. From our survey it is not possible to allocate to a and b proportions of the 403 SYs devoted to GE. Anecdotal evidence, however, indicates that a relatively small proportion of the GE SYs is involved in gene transfer from germplasm accessions. This is a critical issue for several reasons: (a) Are the large World Germplasm Collections really being used in crop breeding? (b) If not, what are the obstacles to their use? (c) By what mechanisms can both private and public sectors contribute to gene-pool enrichment? (d) etc. This is an issue that should be studied on its own merit.

Table 4. Numbers and percentages, in parentheses, of plant breeding SYs devoted to plant breeding research (PBR), germplasm enhancement (GE), and cultivar development (CD) arranged by employer.

Category	SAES	ARS/USDA	Private industry	Activity totals
CD	217 (41%)	22 (12%)	1,191 (80%)	1,430
GE	153 (29%)	85 (48%)	165 (11%)	403
PBR	159 (30%)	70 (40%)	143 (9%)	372
Totals	529	177	1,499	2,205

### Plant Breeding SYs for Various Crops

Data on plant breeding SYs in the United States are presented in several sets of tables. An overall summary is presented by crop category and employer in Table 1. Very detailed summaries are given by plant breeding activity and crop within crop categories in Tables AI through AI 8 for SAES, in Tables BI through BI 16 for ARS/USDA, and in Tables CI through CI 17 for private industry, all in the Appendix of this report. Additionally, summaries are presented for individual crops and employer for 7 crop categories (cereal crops, fiber crops, forage crops, fruit vegetable crops, grain legume crops, oilseed crops, and temperate fruit and nut crops) that each account for more than 100 plant breeding SYs. These summaries are presented in Tables 5 through 11.

In general, it is assumed that private industry will do plant breeding only on crops that can turn a profit from the cultivars developed from their R&D programs. Therefore, of the 219 crops on which breeding is being done in the U.S., the private sector has plant breeding R&D on 144 of them. In fact, private industry reported plant breeding on 42 species for which no breeding is being done in the public sector: These 42 species are spread over 9 crop categories, but a large proportion of them is in the ornamental crop category.

Among the 17 crop categories, cereal crops account for the largest number of plant breeding SYs at 892 (Table 1). This category has 40% of the plant breeding SYs in the United States. Field corn accounts for 545 SYs (Table 5) and 510 SYs (94%) are employed in the private sector. In the SAES and ARS/USDA, the field corn SYs devoted to CD are 3.1 and zero, respectively (Tables AI and 131). The number of SYs devoted to corn breeding in private industry at 510 is 34% of all plant breeding SYs in this employment sector. Also, popcorn and sweet corn breeding are concentrated in the private sector. Eighty-seven percent of the SYs for these 2 types of corn is in the private sector. Wheat accounts for 130 plant breeding SYs overall, and in contrast to field corn, a majority (58%) of wheat SYs is in the public sector. In SAES, 28 wheat SYs are devoted to CD. The public sector continues to support plant breeding of the cereal grains at quite a high level. In SAES and ARS/USDA, 29% and 19% of all plant breeding SYs, respectively, are devoted to cereal crops.

Table 5. SYs devoted to breeding cereal crops arranged by employer.

Crop	SAES	ARS/ USDA	Private industry	Total
Barley	16.4	2.1	13.9	32.40
Dent corn	27.1	8.2	509.75	545.05
Millet	2.55	--	1.7	4.25
Oat	10.1	2.7	4.9	17.70
Popcorn	1.2	0.1	19.4	20.70
Rice	13.8	6.3	21.9	42.00
Rye	0.9	--	0.1	1.00
Sorghum	11.8	2.5	40.8	55.10
Sweet corn	5.35	0.4	27.0	32.75
Triticale	0.85	--	8.15	9.00
Wheat	64.5	11.95	53.95	130.40
Wild rice	0.8	--	1.40	2.20
Totals	155.35	34.25	702.95	892.55

Other crop categories with more than 200 SYs each are fruit vegetable and grain legume crops (Tables 6 and 7). Four crops in the fruit vegetable category each account for 20 or more plant breeding SYs-muskmelon at 23, pepper at 44, tomato at 85, and watermelon at 21. Except for tomato, where the SAES employ 21 SYs, most of the SYs for these 4 crops are in the private sector. In the public sector 72% of the SYs devoted to tomato are in PBR and GE activities, which probably means that it is being used as a model system for PBR in SAES and ARS/USDA.

In the grain legume crop category, soybean accounts for 75% of the plant breeding SYs, and bean, pea, and soybean account for 96% of the SYs (Table 7). SAES have major research inputs into bean with 13 SYs and soybean with 45 SYs. The grain legume category contains 4 crops for which only a single employer type has an R&D program-edamame bean and pigeonpea with SAES programs and faba bean and lupine with private industry programs. True, SYs for none of these crops is large, but some factors help the breeding programs of these crops to survive.

Table 6. SYs devoted to breeding fruit vegetable crops arranged by employer.

Crop	SAES	ARS/ USDA	Private industry	Total
Cucumber	4.6	1.35	8.3	14.25
Eggplant	1.3	--	0.3	1.60
Green bean	--	0.1	9.4	9.50
Muskmelon	0.8	1.55	20.5	22.85
Okra	0.2	--	0.4	0.60
Pepper	5.45	0.5	37.6	43.55
Pumpkin	1.0	--	4.3	5.30
Squash	0.4	--	9.85	10.25
Tomato	20.65	4.55	59.5	84.70
Watermelon	3.6	--	17.2	20.80
Totals	38.00	8.05	167.35	213.40

Table 7. SYs devoted to breeding grain legume crops arranged by employer.

Crop	SAES	ARS/ USDA	Private industry	Total
Adzuki bean	0.4	--	0.1	0.50
Bean	13.3	2.0	8.8	24.10
Chickpea	0.2	0.3	--	0.50
Cowpea	2.6	--	0.75	3.35
Edamame bean	0.1		--	0.10
Faba bean	--	--	0.2	0.20
Lentil	0.1	0.4	--	0.50
Lima bean	0.1	--	0.7	0.80
Lupine	--	--	0.3	0.30
Pea	2.1	1.9	13.9	17.90
Pigeonpea	2.9	--	--	2.90
Soybean	45.0	9.6	101-35	155.95
Totals	66.80	14.20	126.10	207.10

Four other crop categories-fiber, forage, oilseed, and temperate fruit and nut crops-have between 100 and 200 SYs. The fiber crops category has 136 plant breeding SYs, but 134 of these work on cotton (Table 8). Private industry, which accounts for 103 SYs, works only on cotton in the fiber crops category. The SAES and ARS/USDA also have major numbers of SYs (19 and 12, respectively) working on cotton.

Table 8. SYs devoted to breeding fiber crops arranged by employer.

Crop	SAES	ARS/ USDA	Private industry	Total
Cotton	19.15	11.65	103.45	134.25
Crotalaria	--	0.2	--	0.20
Kenaf	0.3	0.8	--	1.10
Poplar	0.2	--	--	0.20
Totals	19.65	12.65	103.45	135.75

The data for the forage crops category have been divided into 2 groups-grasses and legumes (Table 9). Plant breeding SYs in this category are distributed over 19 grasses with 36 SYs and 8 legumes with 86 SYs. There are 2 unusual items about the distribution of SYs in the forage crops category. First, none of the grass species predominates in SYs. Tall fescue with 8.6 has only 24% of the SYs devoted to grass breeding. Second, in spite of the 41 SYs employed by private industry to breed alfalfa, 58% of SYs for forage crop breeding is in the public sector. SAES and ARS/USDA have SYs devoted to 10 grass and 3 legume species that have no private industry input and private industry has SYs devoted to 3 grasses-Klein grass, Reed canarygrass, and sudangrass-that have no public sector input. Despite the fact that plant breeding SYs are distributed over 27 forage crops, 56% of these SYs are devoted to breeding alfalfa-and both employer types (i.e., public and private) contribute major numbers of SYs to this crop.

Table 9. SYs devoted to breeding forage crops arranged by employer.

Crop	SAES	ARS/ USDA	Private industry	Total
Grasses				
Bahiagrass	0.5	0.85	--	1.35
Bermudagrass	0.6	0.2	--	0.80
Big bluestem	0.6	0.95	0.2	1.75
Bluegrass	0.2	0.2	--	0.40
Bromegrass	1.5	0.25	0.35	2.10
Buffelgrass	0.6	0.25	0.2	1.05
Dallisgrass	1.1	0.25	--	1.35
Elephantgrass	0.5	--	--	0.50
Gamagrass	--	2.45	--	2.45
Klein grass	--	--	0.2	0.20
Millet	--	1.5	--	1.50
Orchardgrass	1.8	0.6	1.2	3.60
Reed canarygrass	--	--	0.2	0.20
Ryegrass	0.7	1.2	--	1.90
Switchgrass	0.9	0.25	--	1.15
Sudangrass	--	--	1.2	1.20
Tall fescue	3.6	0.2	4.8	8.60
Timothy	0.5	--	0.1	0.60
Tropical grasses (Misc.)	0.4	--	--	0.40
Wheatgrass	--	4.85	--	4.85
Forage grass totals	13.50	14.00	8.45	35.95
Legumes				
Alfalfa	15.2	11.85	41.0	68.05
Birdsfoot trefoil	0.9	1.7	--	2.60
Cicer	0.1	0.3	0.3	0.70
Clover	5.8	4.9	1.05	11.75
Legumes (Misc.)	0.8	--	--	0.80
Lespediza	0.2	--	--	0.20
Lupine	0.3	--	0.7	1.00
Milkvetch	0.7	0.1	0.1	0.90
Vetch	0.3	--	--	0.30
Forage legume totals	24.30	18.85	43.15	86.30
Totals	37.80	32.85	51.60	122.25

The oilseed and temperate fruit and nut crops categories each have slightly more than 100 plant breeding SYs. In the oilseed category, 3 crops--canola, peanuts, and sunflowers--each have 20 or more plant breeding SYs in the United States (Table 10). Private industry is the major contributor of SYs to canola (81%) and sunflower (91%), whereas the public sector, and primarily SAES, contribute heavily to peanut breeding (84%). As with tomato, the peanut is a crop used heavily in PBR and GE by the public sector--65% of the peanut SYs in the public sector are devoted to these plant breeding activities. The SYs devoted to breeding 4 oilseed crops--plantago, rape, safflower, and samphire--are all in the private sector, whereas all SYs devoted to cuphea, flax, and meadowfoam are in the public sector. The private sector accounts for 71 % of the plant breeding SYs devoted to oilseed crops.

Table 10. SYs devoted to breeding oilseed crops arranged by employer.

Crop	SAES	ARS/ USDA	Private industry	Total
Canola	5.7	1.0	28.0	34.70
Castor bean	1.0	--	2.2	3.20
Cuphea	0.2	--	--	0.20
Flax	1.3	--	--	1.30
Meadowfoam	0.9	--	--	0.90
Mustard	0.5	--	0.3	0.80
Peanut	14.0	2.5	3.15	19.65
Plantago	--	--	0.9	0.90
Rape	--	--	3.0	3.00
Safflower	--	--	4.3	4.30
Samphire	--	--	0.25	0.25
Sunflower	0.6	2.56	31.45	34.61
Totals	24.20	6.06	73.55	103.81

In the temperate fruit and nut crops category, plant breeding SYs are devoted to 20 species, and private industry has plant breeding R&D for 13 of these species (Table 11). One-custard fruit--is bred by private industry only. The crops in this category with the most SYs are strawberry (17), peach (16), grape (11), blueberry (9), and raspberry (9). The public sector accounts for 70% of the SYs breeding temperate fruit and nut crops and SAES contribute 48%.

Table 11. SYs devoted to breeding temperate fruit and nut crops arranged by employer.

Crop	SAES	ARS/ USDA	Private industry	Total
Almond	0.6	--	0.5	1.10
Apple	4.2	--	2.0	6.20
Apricot	0.1	--	1.4	1.50
Blackberry	1.5	1.15	0.5	3.15
Blueberry	4.9	4.55	--	9.45
Cherry	0.5	--	1.2	1.70
Cranberry	0.6	--	--	0.60
Custard fruit	--	--	0.6,	0.60
Grape	7.1	1.45	2.4	10.95
Kiwi	0.3	--	--	0.30
Nectarine	0.9	0.45	3.8	5.15
Papaw	1.0	--	--	1.00
Peach	5.9	4.8	5.7	16.40
Pear	5.1	2.3	0.7	8.10
Pecan	1.0	1.4	--	2.40
Pistachio	1.0	--	--	1.00
Plum	0.7	4.1	3.1	7.90
Raspberry	6.7	0.15	2.5	9.35
Strawberry	7.4	2.3	6.9	16.60
Walnut	0.9	--	--	0.90
Fruit crops (Misc.)	--	--	0.6	0.60
Totals	50.40	22.65	31.90	104.95

In the lawn and turf grass crops category there are 55 plant breeding SYs (Tables A6, B6, and C6). ARS/USDA has only 0.2 SYs on bermudagrass, and private industry provides 73% of the SYs -in this category. Ryegrass and bluegrass with 13 and 15 SYs, respectively, are the lawn and turf grasses with the most breeding effort. There are 95 plant breeding SYs devoted to leafy, bulbous, and stem vegetable crops (Tables A7, B7, and C7) and 77 SYs (81 %) are in the private sector. ARS/USDA has only 2.2 SYs devoted to this crop category. Lettuce and onion with 24 and 26 SYs, respectively, have 53% of the SYs in this crop category. The breeding programs of 4 crops in this category-garlic, globe artichoke, kohlrabi, and Swiss chard-all are in the private sector, but their total SYs is only 3.5.

In the medicinal, spice, and special crops category the total SYs is 15, and the number of crops is 12 (Tables A8, B8, and C8). No crop has more than 4 SYs. Private industry breeds 3 unique crops-cactus pear, fennel, and thyme. For mushrooms, there are 2.5 SYs and 3 types of mushrooms with breeding programs (Tables A9 and C9). There are 81 SYs devoted to breeding of root and tuber crops (Tables AI 2, BI 1, CI 2) and 29% of

these SYs are in private industry. Fifty and 13 of the plant breeding SYs are devoted to potatoes and sweet potatoes, respectively, and 54 of these are employed in the public sector. Three stimulant crops are bred in the U.S.-tobacco, cocoa, and coffee-and tobacco is responsible for all but 1. 1 of 19 SYs devoted to these crops (Tables AI 3, 1312, and CI 3). Eighty percent of the tobacco SYs are in the public sector, primarily in SAES: However, 80% of public sector SYs on tobacco are in PBR and GE, indicating that this crop is used as a model for plant breeding studies.

In the sugar crops category there are 44 plant breeding SYs and 36 of these breed sugar beets (Tables A14, 1313, and C14). ARS/USDA employs 10.8 SYs on sugar beets, all working on PBR and GE, whereas 93% of the private industry 24 SYs on sugar beets are in CID. Tropical fruit and nut crops can be grown in only a limited number of areas in the U.S.-Puerto Rico, Virgin Islands, Hawaii, Florida, and southern Texas and California: Therefore, breeding on these crops is quite limited in the U.S. Only 16 SYs are devoted to breeding tropical fruit and nut crops and private industry employs 0.2 of these to breed mango (Tables A16, 1315, and CI 6).

### **Crops With Most SYs in Plant Breeding**

Over both private and public sectors of plant breeding, 545 SYs are devoted to field corn breeding, and 94% of these SYs are in private sector employment (Table 12). Also, this equals 25% of all plant breeding SYs in the United States. Other crops with more than 100 SYs are soybean, cotton, and wheat. The employment categories for soybean and cotton is quite different from that for wheat, however. For soybean, 65% of SYs is in private industry; for cotton this value is 77%; but for wheat only 41% is in private industry. The commercial acreages of these crops are dominated by pure line cultivars, so the contrast in public/private employment between soybean and cotton vs. that in wheat represents an interesting anomaly. Crops with between 50 and 100 plant breeding SYs are potato, sorghum, alfalfa, and tomato-here again, these 4 crops represent a contrast in public/private SY input. For sorghum, alfalfa, and tomato, the private companies employ from 60 to 73% of the plant breeding SYs, whereas for potato, private industry employs only 18% of the SYs. These crops are quite contrasting in cultivar types used on commercial acreages in the United States-the commercial acreage of sorghum is entirely hybrid, that of alfalfa is sown to synthetics, that of tomato is half hybrid and half pure line, and the potato acreage is sown to clonal cultivars.

Table 12. Crops in which 25 or more breeding SYs are employed in the United States.

Crop	Number of SYs			Total
	SAES	ARS/ USDA	Private industry	
Alfalfa	15	12	41	68
Barley	16	2	14	32
Canola	6	1	28	35
Cotton	19	12	103	134
Field corn	27	8	510	545
Onion	4	1	21	26
Pepper	5	1	38	44
Potato	31	10	9	50
Rice	14	6	22	42
Sorghum	12	3	41	56
Soybean	45	10	101	156
Sugar beet	1	11	24	36
Sunflower	1	3	31	35
Sweet corn	5	1	27	33
Tomato	21	4	60	85
Wheat	65	12	54	131

Crops for which private industry employs 20 or more plant breeding SYs are presented in Table 13. There are 510 SYs doing corn breeding for 91 companies in the United States. Private industry also has more than 100 plant breeding SYs for each of cotton and soybean. Overall, private industry employs 20 or more breeding SYs on 16 different crops. The number of SYs devoted to breeding these 16 crops by private industry is 1,142. In the previous section, it was noted that private sector has breeding R&D on 144 species, but 76% of the private sector SYs in plant breeding is devoted to the 16 crops listed in Table 13.

Table 13. Crops for which 20 or more breeding SYs are employed in private industry in the United States.

Crop	Cultivar Type	Number of Sys	Number of companies
Field corn	H	510	91
Cotton	PL	103	35
Soybean	PL	101	38
Tomato	1/2 H / 1/2 PL	60	24
Wheat	PL	54	27
Alfalfa	S	41	12
Sorghum	H	41	19
Pepper	1/2 H / 1/2 PL	38	27
Sunflower	H	31	14
Canola	PL	28	4
Sweet corn	H	27	12
Sugar beet	H	24	7
Rice	PL	22	8
Onion	1/2 H / 1/2 PL	21	13
Muskmelon	H	21	15
Lettuce	PL	20	18

H = hybrid; PL pure line; S = synthetic.

It is commonly acknowledged that private company plant breeding began with the breeding of hybrid corn, primarily because seed of hybrid cultivars must be repurchased each year. Also, a private company can maintain its monopoly on a hybrid by not releasing the parent stocks used to make the hybrid. Of the 16 crops listed in Table 13, hybrids are sown on the entire commercial acreage of field corn, sorghum, sunflower, sweet corn, sugar beet, and muskmelon, which collectively account for 654 private industry SYs. Currently, the commercial acreage of tomato, pepper, and onion is about evenly divided between hybrid and pure line cultivars: These crops account for 119 breeding SYs in private industry. The commercial acreages of cotton, soybean, wheat, canola, rice, and lettuce are sown entirely to pure line cultivars, and these crops account for 328 SYs in private plant breeding. Seed of cultivars of these crops can be replanted by a farmer year after year without genetic deterioration, so to insure repeated sales of these crops, private companies must protect their cultivars via Plant Variety Protection or patents. The ratio of private industry SYs devoted to hybrid cultivar development shows that hybrid breeding is a significant factor in the success of plant breeding by private companies.

The crops with 15 or more plant breeding SYs in public sector employment are given in Table 14. Wheat, soybean, and potato have 40 or more breeding SYs in the public sector; the remaining 8 crops have from 15 to 35 SYs each. Pure line is the cultivar type for 7 of the 11 crops with a total of 233 SYs. Few of the 35 public sector SYs on field corn develop hybrids; in fact, 32 SYs are devoted to PBR and GE activities for corn. The case of potato is unique in that clonal cultivars are used to plant commercial acreages

of this crop. Of the 50 breeding SYs for potato, 41 are employed in the public sector, and 18 of these 41 SYs are devoted to CD. Obviously, the public sector has nearly divested itself from breeding hybrid cultivars, of crops; on the other hand, plant breeding in private industry is heavily devoted to hybrid CD.

Table 14. Crops in which 15 or more breeding SYs are employed in SAES and ARS/USDA.

Crop	Cultivar type	Number of SYs in		Total	No. of projects
		SAES	ARS/ USDA		
Wheat	PL	65	12	77	42
Soybean	PL	45	10	55	32
Potato	C	31	10	41	28
Field corn	H	27	8	35	32
Cotton	PL	19	12	31	20
Alfalfa	S	15	12	27	25
Tomato	1/2 H / 1/2 PL	21	4	25	28
Rice	PL	14	6	20	15
Barley	PL	16	2	18	24
Peanut	PL	14	3	17	11
Bean	PL	13	2	15	14

H = hybrid; PL pure line; S = synthetic; C = clone.

#### Annual Dollar Input into Plant Breeding

The cost per plant breeding SY in the private sector varied according to company size (Table 15). The cost per SY was \$290,000 for companies with 25 or more SYs and was \$148,000 per SY for companies with 2.9 or less. There was a somewhat linear regression for the other classes. Overall, the 329 companies that do plant breeding have an annual expenditure of about \$338 million for R&D. Kalton et al. (1989) estimated that the private sector was spending \$272 million on plant breeding R&D in 1989. Their estimates were obtained by asking the companies surveyed how much they spent on R&D.

The public sector is estimated to spend \$213 million annually on plant breeding R&D (Table 16). Nearly three-quarters of this amount is expended by SAES. The total research expenditure for SAES and cooperators in 1994 was \$2,132 million, and the expenditure for crops research was \$720 million. Therefore, SAES estimated expenditure for planting breeding R&D represents 7.3% of the total SAES budget and 21.5% of the crops budget. Comparable data for ARS/USDA are \$1,144 million for all research and \$418 million for crops research: The ARS/USDA expenditure of \$53.1 million for plant breeding is 4.6% of total research expenditure and 12.7% of the crops research expenditure. The total estimated expenditure for plant breeding annually in the United States is \$551 million with 61 % from the private sector and 39% from the public sector.

Table 15. Cost per SY, number of companies, total SYs, and dollar input into plant breeding R&D by private industry arranged according to company SY size.

Company class in SYs	No. of companies	Cost per SY	Total no. of SYs in class	Dollar input for class
25.0 – up	10	\$290,000	466.2	\$ 135,198,000
15.0 - 24.9	5	\$228,000	90.6	\$ 20,657,000
10.0 -14.9	20	\$240,500	235.75	\$ 56,697,875
5.0 - 9.9	43	\$186,000	286.7	\$ 53,326,200
3.0 - 4.9	43	\$217,000	153.1	\$ 33,222,700
0 - 2.9	208	\$148,000	265.95	\$ 39,360,600
Totals	329		1,498.30	\$ 338,462,375 <sup>4</sup>

<sup>4</sup> If the estimated 36 SYs for companies that did not reply (see Methods and Materials) were included, \$7.8 million would be added to the private sector expenditure.

Table 16. Cost per SY, total SYs, and dollar input into plant breeding R&D by the public sector arranged according to source of public sector employment.

Employment source	Cost per SY	Total number of Sys	Dollar input for source
ARS/USDA	\$300,000	177.0	\$ 53,100,000
Plant Materials Center	\$125,000	36.2	\$ 4,525,000
SAES	\$293,500	529.9	\$155,525,650
Totals		743.10	\$213,150,65

## REFERENCES

Brooks, H. J., and G. Vest. 1985. Public programs on genetics and breeding of horticultural crops in the United States. *HortScience* 20:826-830.

Collins, W. W., and R. L. Phillips. 1991. Plant breeding training in public institutions in the United States. Report 591 (Rev.). National Plant Genetic Resources Board. Office of Under Secretary for Science and Education, U.S. Department of Agriculture, Washington, DC.

CSREES. 1995. Inventory of agricultural research-Fiscal Year 1994 Current Research Information System. Cooperative State Research, Education, and Extension Service, Science and Education Resources Development, U.S. Department of Agriculture, Washington, DC.

James, N. 1. 1990. A survey of public plant breeding programs in the United States, 1989. *Diversity* 6:32-33.

Kalton, R. R., and P. A. Richardson. 1983. Private sector plant breeding programs: A major thrust in U.S. agriculture. *Diversity*, Nov.-Dec., pp. 16-18.

Kalton, R. R., P. A. Richardson, and N. M. Frey. 1989. Inputs in private sector plant breeding and biotechnology research programs in the United States. *Diversity* 5(4):22-25.

## Appendix D [Appendices A, B, and C are in the associated spreadsheet]

Questionnaire used in survey.

### INSTRUCTIONS

The questionnaire is arranged in two parts-

**PART A** is a request for general information about the organization for which you work. Instructions for completing answers to individual questions are given in the box under Part A.

**PART B** is arranged to report Science Person Years (SY) devoted to plant breeding research, germplasm enhancement, and cultivar development for individual crops. Please report to the tenth (0.1) of a SY for each crop you list.

### DEFINITIONS

Science Person Year-Work done by a person who has responsibility for designing, planning, administering (managing), and conducting (a) plant breeding research, (b) germplasm enhancement, and (c) cultivar development in one (1) year (i.e., 2,080 hours). DO NOT include technicians, farm and clerical workers, computer specialists, post docs, grad students, etc.

**Plant Breeding Research**-Research on the genetics of plants and methodologies of plant breeding and biotechnology usually done to provide fundamental information useful for making plant breeding more efficient and productive. DO NOT include basic research on plant molecular biology.

**Germplasm Enhancement**-Any activity that includes (a) gene transfer via sexual and asexual means from germplasm accessions and (b) increasing the frequencies of desirable genes in crop gene pools that will be used for developing parents or cultivars.

**Cultivar Development**-Any activity -of crossing, transformation, and/or selection (including marker-assisted selection) among plants which has the direct purpose of releasing a crop variety.

**PART A. General Information About Your Organization**

Please use fiscal year 1994 as the base time period for reporting answers to the following questions.

Circle one number or enter a response for each question.

1. Are you reporting for ...  
1 =USDA  
2=State experiment station  
3=Private company  
4=Some other organization\_\_\_\_\_ (explain)
2. How many years has your organization been involved in plant breeding research, germplasm enhancement, and/or cultivar development?  
\_\_\_\_\_ Years
3. a) Over the past five years, has the SYs your organization devoted collectively to plant breeding research, germplasm enhancement, and/or cultivar development-  
  
1 =Decreased  
2=Stayed the same (if stayed the same, go to Part B)  
3=Increased  
  
b) By how much? \_\_\_\_\_%

**PART B. Report of Science Person Years (SY) by Crop**

Please report the trends in the number of SYs [(to the nearest tenth (0.1))] your organization devoted to plant breeding research, germplasm enhancement, and/or cultivar development on a crop basis in 1994 (see DEFINITIONS in INSTRUCTIONS, page 44)

In 1994 the SYs your organization devoted to:

Crop Name	Plant Breeding Research	Germplasm Enhancement	Cultivar Development
Use one line for each crop (refer to Reference of Crops list)			
Wheat	2.3	0.5	4.2